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LOCATION OF SOLID WASTE DISPOSAL FACILITIES IN URBAN COMMUNITIES

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ABSTRACT

Due to the ever increasing volume of solid wastes, solid waste disposal has become one of the many problems facing American cities serious enough to require federal legislation. Because of this fact, and in view of the public controversy which so often accompanies selection of disposal sites, this study was undertaken to produce a guide for city planners, sanitation departments, private disposal companies, and others involved in deciding where solid waste disposal facilities should be located in urban areas. All the significant disposal methods including burial, salvage, reduction, composting, incineration, hog feeding, open burning, open dumping, garbage grinding, sanitary landfill, and dumping at sea are discussed with regard to the site requirements and operating characteristics which must be considered when deciding where to locate a disposal facility. This discussion forms a basis for the detailed analysis of considerations in locating disposal facilities. Also, the factors to be considered in selecting a disposal method are briefly described.

The primary considerations in locating disposal facilities in urban areas are: (1) protection of surrounding land uses, and (2) economic considerations, including collection costs, initial site costs,

and co-ordination with other utilities. In locating sanitary landfills the site's geology, the effects of filling, and the future use of the site should also receive careful consideration. In taking these factors into account certain planning studies should be undertaken. These include a solid waste disposal facilities study, a site survey, a land use study, a geologic survey, a transportation study, and an economic analysis.

In order to provide the public with satisfactory, nuisance free refuse disposal service at the lowest possible cost, it is recommended that the following steps be taken: (1) only those disposal methods should be used which will effect absolutely nuisance free disposal of refuse, and (2) state enabling legislation should be obtained to allow planning, establishing, and financing of refuse disposal on a regional basis in metropolitan areas.

CHAPTER I

INTRODUCTION

The provision of means and facilities for satisfactory, nuisance free disposal of solid wastes, including garbage, rubbish, and demolition wastes, is a problem of increasing seriousness in both urban and rural communities. The public is beginning to demand that the smoke, odors, dirt and dust, vermin, and insects long associated with solid waste disposal be eliminated.

The Solid Waste Problem Today

Urbanization has made individual responsibility for waste disposal unacceptable. Today, every community must provide for a sanitary system of refuse disposal. This is a tremendous undertaking requiring heavy equipment and skilled management and engineering, the cost of which is exceeded only by expenditures for schools and roadways.[1]

Solid waste disposal has become such a serious problem that in 1965 Congress passed the "Solid Waste Disposal Act." Congress found that:

> ...the problems of waste disposal have become a matter national in scope and in concern and necessitate Federal

action through financial and technical assistance and leadership in the development, demonstration and application of new and improved methods and processes to reduce the amount of waste and unsalvagable materials and to provide for proper and economical solid-waste disposal practices.[2]

Our solid waste problem is tied to the production and consumption of our technological society. The output of domestic solid wastes is estimated at 1,600 pounds per capita per year, or 4.5 pounds per capita per day. Altogether we are producing 300 billion pounds of solid wastes per year for which the collection and disposal costs are estimated to be 1.5 to 2.5 billion dollars.[3]

The solid wastes which are produced by a community and require physical removal and disposal are called refuse. Refuse is generally composed of the following:

Garbage - putrescible wastes resulting from the growing, handling, preparation, cooking and consumption of food.

Rubbish - all nonputrescible wastes except ashes, such as cans, paper, brush, glass, cardboard, wood, scrap metal, and yard clippings.

Ashes - the waste produced from burning coal and other fuels.

Other solid wastes often disposed of by municipalities are dead animals, street sweepings, and industrial wastes. For the purpose of this thesis junked automobiles are not considered as refuse.

If present trends continue, per capita refuse production will rise to 5.9 pounds per day in 1985.[4] Innovations in marketing and packaging are producing more disposable articles and containers. The American desire for and increased ability to maintain "newness" results in an increased rate of discarding, and increasing total per capita volumes of refuse. However, collections of garbage are declining as more and more garbage is ground in the home and discharged into the sewers. Because of the shift to oil and natural gas for heating purposes ashes are no longer a significant component of domestic refuse.

Disposal of refuse is a problem in urban areas because disposal operations are often accompanied by noise, smoke, dust, unsightliness, and heavy truck traffic which can make such operations incompatible with some types of development, especially residential. To avoid this problem by prohibiting refuse disposal within a municipality is a flagrant contradiction to needs. Instead, the conflicts between urban development and refuse disposal should be resolved through good planning by the local government.

Scope and Purpose

The objective of this thesis is to propose methods which can be used by city planners, sanitation departments, and private disposal companies to promote a more compatible relationship between solid waste disposal and orderly urban development. This objective was accomplished by determining the disposal methods available for use in urban areas, by reviewing the operating procedures of the various disposal methods, and by analyzing those characteristics of different disposal methods which affect their location.

The following chapters outline generally the possible disposal methods and the factors affecting their location in the average community. One must remember that no two communities are ever precisely alike, and that a refuse disposal site can be selected only after careful study of the individual municipality. However, by applying the information given in this thesis, the planner should be better able to decide on a disposal method and a site likely to be satisfactory in his own particular community.

Information for this study was obtained from a review of pertinent literature, examination of selected disposal facilities, and interviews or correspondence with persons or agencies with knowledge about solid waste disposal.

CHAPTER II

DISPOSAL METHODS AND CHARACTERISTICS

The purpose of this chapter is to provide a general understanding of the advantages, disadvantages, operating characteristics, and site requirements of various solid waste disposal methods. No attempt is made to present a detailed, technical description of the disposal operations.

Open Dumping

Open dumping is the easiest and least expensive method of refuse disposal. It simply involves the dumping of collected refuse at a site set aside for that purpose. While it is the cheapest method of waste disposal, open dumping has many serious limitations.

Some components of refuse, including street sweepings, ashes, and incombustible rubbish, are suitable for open dumping. Serious nuisances and health hazards will result, however, if garbage or mixed refuse is disposed of in this manner. Burning, which generally occurs, emits excessive smoke and odors. Because dumps are not protected from the normal effects of rainfall, refuse materials or their contaminated solutions are often washed out of the dump and into nearby streams causing water pollution. Dust, blowing papers, unsightliness, and rodent and insect or vector breeding are common.

Land area requirements for a dump are high, and the value of contiguous land is depressed. Dumps where burning is banned and which are occasionally "worked" by a bulldozer are less offensive than those which are not maintained. Nevertheless, even the best dump is an unsatisfactory solution to the problem of community waste disposal.

Hog Feeding

Feeding garbage to hogs can be a profitable operation, and at one time many cities operated hog farms. But, only garbage can be disposed of in this manner. The garbage must be collected separately, adding to collection costs, and the problem of disposing of the majority of refuse remains unsolved. Also, trichinosis and vesicular exanthema, a swine disease, are both spread through uncooked garbage. A severe outbreak of the latter disease in 1952 brought laws in every state requiring that garbage fed to hogs be cooked. Although partially offset by an increase in hog weight, this requirement has substantially added to feeding costs.

The difficulty of operating hog ranches free from nuisances and sanitation hazards makes them an unwelcome part of an urban community. Even a properly operated hog ranch should be located at least one mile from the nearest residential area.[5] Thus, in many parts of the country rapidly advancing development is either forcing the abandonment of hog ranches or pushing them out into sparsely inhabited areas. The increased haul distance adds to collection costs already high due to the necessity for separate collection of garbage.

Because of the nuisance problem and the reduced economic incentive, feeding garbage to hogs is not generally a satisfactory method of disposal. In some cases, however, it is still a good method for disposing of the large quantities of garbage produced by restaurants and institutions.

Sanitary Landfill

Sanitary landfill differs from open dumping in that landfill involves the orderly burying of refuse on a strict daily basis. The three basic methods of landfill are the area-fill method, the area-ramp method, and the trench method. The method selected depends on the terrain and soil characteristics of the landfill site. Area-fill requires the acquisition of cover material from off the site, or from the site's periphery in the case of a canyon site. Trenching and the area-ramp method provide on-site cover material.

Both methods follow a common pattern. Refuse is deposited in a trench or other prepared area and immediately compacted by a suitable compaction machine, such as a crawler type tractor. After the refuse is deposited and compacted it is covered daily with a six inch layer of compacted earth. As an area becomes completely filled a 24 inch layer of earth is placed as a final cover.

Considerable satisfactory experience has been had with the landfill method of refuse disposal. During the last 20 years more than 1,400 cities and counties throughout the country have used this method under a variety of local conditions.[6] Burning is eliminated and odors are sealed in so that air pollution does not occur. Rodents and insects are not a problem since covering procedures afford them no opportunity to breed. Numerous cases have been reported of properly operated landfills being located near residential neighborhoods with no complaints.[7,8]

While not necessarily located on sub-marginal land, a sanitary landfill is a means of reclaiming such land. The increased value of reclaimed property should more than offset acquisition costs.

Other advantages are simplicity, economy, and flexibility. Of all the acceptable methods of waste disposal, a landfill usually involves the least direct cost to the community. Satisfactory disposal can usually be accomplished for $1.00 to $2.50 per ton of refuse, depending on the size of the operation, availability of cover material, and other local conditions. A landfill operation can be started in a short time, and no great additional expense is necessary to handle increased amounts of waste. Smaller cities can often use landfill equipment for other purposes for part of the day. Unlike other methods, the landfill offers facilities for disposal of practically all types of refuse.

The chief disadvantage of disposal by landfill is the large land area required. The refuse produced by a population of 10,000 will fill about 12 acre feet per year.[9] An additional 15 to 25 per cent must be allowed if imported cover is used. In addition, unless the operation is carefully planned, problems may develop during inclement weather.

In some cases there are no suitable landfill sites available within economical hauling distance of the city. Generally, costs for hauling refuse to the disposal site in excess of $1.50 per ton cannot be justified.[10] If collection trucks must travel more than 10 to 15 miles farther to a sanitary landfill site than to an incinerator, for example, incineration may be a less expensive disposal method.

The distance at which the haul cost makes the total cost of disposal by landfill greater than the cost of other disposal methods can be increased to between 25 and 40 miles by using transfer stations.[11] At a transfer station refuse is emptied from the collection trucks into much larger trucks for the haul to the disposal site.

The simplest and least expensive transfer method is the direct dump system. A differential elevation is created so that collection vehicles can dump directly into the transfer trucks. This method is limited to single shift operation paralleling the collection period.

A second transfer method uses a bulldozer to push the refuse into the transfer trucks after the refuse has been dumped onto an elevated loading dock. This method allows transfer operations to be carried on about 12 hours a day, but it requires a bulldozer and operator. Also, the operation is unsightly and can result in wind-scattered refuse and possible rodent and insect vector infestations.

The third type of transfer operation utilizes a refuse storage pit and a bridge crane for loading. This method is used for around the clock transfer operations. It becomes economically competitive at a capacity of about 500 tons per day.[12]

A transfer station with a 24 hour capacity of 200 tons would occupy a minimum of one-half acre.

Some communities have encountered difficulties with the fill itself. Settling, methane gas formation, and ground water pollution can occur if the landfill is improperly located or operated. Generally, however, the sanitary landfill is a very satisfactory disposal method.

Incineration

Incineration is the controlled combustion of refuse in specially designed furnaces. Burning temperatures must be maintained between 1,400 and 2,000 degrees Fahrenheit to prevent the smoke and odors which result from incomplete combustion.

Only a small site of about 250 square feet per ton of rated capacity is required for an incinerator, and it is compatible with many types of land use. A hill side site will reduce construction costs for a direct charge or bin and crane plant. Greater flexibility of location means that haul distances can be minimized. The volume of refuse is greatly reduced and the residue is a much more acceptable fill material than unburned refuse. Also, an incinerator is unaffected by climate or unusual weather, and it may be possible to utilize the waste heat generated.

Unfortunately, incineration is an expensive method of refuse disposal with costs generally ranging from $3.00 to $5.00 per ton of refuse burned. Capital costs are also high--usually $3,000 to $5,000 per ton of rated 24 hour burning capacity. The cost of disposing of incinerator residue must be added to the actual incineration costs. However, it may be possible to sell or give the residue away for use as fill material. Occasionally other byproducts such as tin cans can likewise be sold to offset part of the incinerator operating costs.

Incineration costs can be substantially increased for cities located in areas which frequently experience thermal inversions and, consequently, have air pollution problems. Often stack emissions can be reduced to acceptable levels only at great expense.

The City of New York recently spent $400, 000 to install an electrostatic precipitator on one of its incinerators.[13]

Composting

Composting is a biochemical process which alters the composition of organic materials into a stable, humus-like end product. The process does not produce atmospheric emissions, nor does it create water pollution problems. About 70 per cent of a city's refuse is compostable.

The two general methods of modern refuse composting are windrow composting and mechanical digestion. The first step in both methods is to separate out noncompostables such as metal and glass for salvage or further disposal. In windrow composting the refuse is piled into windrows about five feet high. The first large scale composting process was the Indore process.[14] In this process refuse is piled in alternate layers with sewage sludge or manure and turned twice during a period of six months. Several modifications of this process have been developed, involving more frequent turning or an initial anaerobic digestion stage. Today, the most popular windrow process is the rasping system. The refuse is first ground up, then piled into windrows and turned every day or two. This process requires about three weeks. Windrow composting costs only \$2.00 to \$3.00 per ton,[15] but large sites are required. Between 10 and 50 acres would be needed to serve a population of 500,000, depending upon which process was used. In the mechanical process, after noncompostables are separated out, the refuse is shredded and blended to achieve a moisture and nitrogen content within the desirable range. Digestion takes place under aerobic conditions in an enclosed structure where moisture, temperature, and ventilation are carefully regulated. The most popular mechanical process, the Dano Biostabilizer System, utilizes an inclined, slowly revolving cylinder through which the ground refuse passes over a four to six day period. Mechanical plants are compact and can be located without offense in any industrial section.

Compost is a useful fertilizer and soil conditioner, but the extensive handling required makes the composting process expensive. The American cost of a Dano composting plant is estimated at \$2.88 per ton of refuse composted.[16] Actual experience with composting in this country has been very limited. However, Elmira, New York, contracted for disposal of 70 tons of refuse per day by a mechanical composting process at a cost of \$4.35 per ton.[17] Houston, Texas, recently awarded a similar contract for disposal of 300 tons per day for \$3.51 per ton.[18]

Due to the availability of cheap inorganic fertilizers in this country, there has been no widespread demand for compost. But, if the compost can be sold at some price, or at least disposed of at no additional cost to the city, composting is competitive with incineration, and in some cases may be less expensive than sanitary landfill.

Salvage

Obviously the solid waste problem could be simplified if the volume of waste products was reduced by salvage or reclamation. But many salvage operations which were profitable a number of years ago have been made uneconomical by falling markets and rising labor costs.

Despite these difficulties, salvage, especially of metals, is still an important industry. An average of 26.6 million tons of scrap per year was purchased by the steel industry during the period 1958 to 1963.[19] Nearly all nonferrous metals are eventually salvaged for reuse, with the salvage of lead, copper, and aluminum being particularly important.

Salvage is most readily carried out when the waste material is homogeneous, as from commercial and industrial operations. When salvable material is mixed with garbage and other refuse, reclamation is generally uneconomical since hand sorting becomes necessary. Yet, because of convenience to the householder and lower cost of collection, the trend is toward combined collection of domestic wastes.

Salvage operators are also experiencing difficulty in keeping their collection points in operation. Salvage operations are often unsightly and sources of dust, noise, and odors. Urban renewal and zoning regulations have tended to displace rag, glass, paper and scrap metal collectors and make it difficult for them to relocate satisfactorily. As a result, the number of waste material collectors is decreasing.[20]

On-Site Disposal

On-site disposal refers to the disposal of refuse at the place of origin. Methods include garbage grinding, incineration, burial, and open burning. If on-site disposal could be used for all solid wastes, the whole problem of collecting refuse and operating community disposal facilities would be eliminated. But this is not possible at present.

Garbage Grinding

Garbage placed in a home garbage grinder is shredded and discharged into a sewer. The advantage of garbage grinders is their convenience to the householder and the reduction of fly and rodent breeding. Garbage is only a small fraction of all domestic wastes, but it is the source of many of the odor and health problems associated with solid waste disposal.

The most significant effect of discharging garbage into the sewers is a 35 to 45 per cent increase in suspended solids.[21] This requires additional digester capacity at the sewage disposal plant, and digester-gas production increases 50 to 100 per cent.[22] Garbage in the sewers is carried without difficulty in a properly designed system, although it is necessary to contend with grease accumulations in gas traps and pump impellers.

The use of garbage grinders has been banned in some cities. This may be advisable where the sewage disposal system is inadequate. In such cases, until the sewerage system is improved, grinding garbage into the sewers would only increase water pollution.

Incineration

The single chamber incinerators often used for on-site disposal are especially offensive pollution sources. Unlike the multiple chamber incinerator, the single chamber unit has no afterburner where burning of the gases produced in the initial combustion process can be completed. One ton of refuse burned in a single chamber incinerator may produce up to 25 pounds of dust, 300 pounds of hydrocarbons, and 1,000 pounds of carbon monoxide, compared to three pounds, one-quarter pound, and one-half pound respectively from a multiple chamber incinerator.[23] In 1958 the Los Angeles Air Pollution Control Board closed down $58 million worth of single chamber incinerators. The county began hauling refuse as far as 40 miles to landfill sites.[24]

Even a well-designed small incinerator is unlikely to be properly operated by the householder, and an improperly fired incinerator causes odors and air pollution. Combustion is often incomplete, leaving garbage that will attract flies and rodents. A recent survey of 20,000 home incinerators revealed that only one per cent met air pollution standards.[25] Air pollution problems, fire hazards, and the difficulty of regulating the maintenance and operation of large numbers of home incinerators have caused them to be banned in many cities.

Use of apartment building incinerators reduces substantially the volume of refuse which must be disposed of at community facilities, but it may likewise result in serious air pollution. Prohibition of such incinerators eliminates air pollution, but it may create problems of refuse storage and collection. However, the design of apartment type incinerators is continually improving. Better design and more effective operation may reduce pollution from apartment incinerators to acceptable levels.

Burial and Open Burning

Burial and open burning are the common methods of refuse disposal in rural areas, and open backyard burning is also widely practiced in urbanized areas. Both methods invite nuisance conditions in an urban community. Burial provides satisfactory protection for public health only if the refuse is covered with a compacted layer of earth deep enough to prevent fly emergence and to keep the refuse from being dug up by animals searching for food. In urban communities open burning is not an acceptable method of refuse disposal since it encourages fly and rodent breeding, and is a source of smoke and odors which contribute to air pollution.

Other Methods

There are several additional methods of waste disposal which should not be overlooked. Some of these are new, untested methods, while others have proven unsatisfactory in the past.

Dumping at Sea

Ocean disposal was used by the City of New York between 1890 and the 1930's. Pollution of New Jersey beaches finally became so bad that New York's ocean disposal program was ended by a United States Supreme Court decision in 1934.[26]

Consideration has been given to the possibility of compacting refuse into dense bales which could not float and dumping them at sea. The possibility of burning the refuse at sea and dumping the residue has also been discussed. However, the long haul offshore necessary to avoid pollution and the present cost of baling make both these methods uneconomical.[27] Too, the variations in sea and weather conditions would cause problems in achieving the degree of reliability necessary for a municipal refuse disposal operation.

Grinding and Disposal in Sewers

It has been proposed that not just garbage, but rather all combustible refuse be ground and discharged into the sewers. This method utilizes existing sanitary sewers for transporting wastes to the disposal point. There is no air pollution problem, and all organic wastes are reclaimed as sewage sludge. Properly located grinding stations can minimize haul distances for collection vehicles.

Experience with this method of disposal is negligible and much is unknown. Water pollution problems might be worsened since BOD increases up to 300 per cent. The BOD, or biochemical oxygen demand, is the amount of oxygen which is required for decomposition of sewage solids into stable compounds. Hydrogen sulfide generation in sewers also increases. Slower digestion of the sewage sludge might be another problem.[28] It is necessary to provide additional facilities for disposal of metalic and glass refuse, which constitutes about 30 per cent of the total.

Unless excess treatment capacity already exists, additional sewage treatment facilities are necessary. These facilities will require a capital outlay of about $5,600 per ton of refuse ground per day. The cost of operating and amortizing the grinding and treatment facilities is estimated at $2.64 per ton.[29] To this must be added any increase in sewage system operating costs. These costs might be offset somewhat by using or selling the increased volume of digester gas.

Reduction

Reduction is a process for converting garbage and dead animals into grease and tankage. As with other processes for disposal of garbage only, separate collection is necessary. Wide fluctuations in the market for grease and tankage make it hazardous to invest in the expensive equipment required. Another difficulty is finding an appropriate site, since a rendering plant produces odors and nuisances which are difficult and costly to suppress.

CHAPTER III

PLANNING FOR DISPOSAL FACILITIES

Since every urban community produces solid wastes which must be disposed of somewhere, and since waste disposal is often a problem land use, the location of disposal facilities should be carefully planned. Unless workable plans are made and implemented it will be necessary to haul refuse increasingly greater distances for disposal. In this chapter a brief discussion of considerations that should be observed in choosing a disposal method is followed by a presentation of those factors to be considered in locating solid waste disposal facilities. Finally, specific planning studies for locating disposal facilities are outlined.

Selecting a Disposal Method

The basic considerations in selecting a method for disposal of solid wastes are: (1) the absence of danger to public health, (2) minimum nuisance to the public, and (3) minimum cost for the sanitary disposal of all solid wastes.[30] Before a community selects a disposal method, several studies should be made to determine which method best meets these criteria. Naturally, methods which cannot meet these criteria under any conditions, such as open dumping and dumping at sea, are excluded from consideration.

Disposal Practices Survey

Local governments should conduct periodic surveys of solid waste disposal practices, particularly in growing areas, to determine whether the above criteria are being met. If not, then a different waste disposal system should be selected and put into operation.

As an area becomes more densely populated, on-site disposal by burial and open burning will begin to cause nuisances. When insect and rodent breeding and smoke and odor generation become problems, on-site burial and open burning of wastes should be banned.

In urbanizing areas the location and operation of hog ranches, salvage yards, rendering plants, and similar disposal facilities must also be closely regulated in order to eliminate health hazards and minimize nuisances. These facilities are highly undesirable in or near residential areas. Unless effective odor control can be established, rendering plants, and to a lesser extent hog ranches, require an isolated location because of the unpleasant odors commonly generated.

Soil Survey

A general soil survey can determine whether suitable sites for a sanitary landfill exist in the area. In some cases a high water table, rocky soils, or soils underlain by rock at a shallow depth may preclude disposal by sanitary landfill. It is recommended that the depth to ground water or rock be greater than four feet from the bottom of the fill material.[31] Where more suitable landfill sites are not available, a different disposal method should be used.

Air Pollution Survey

Communities which have not already done so should determine the quality of air supply which they wish to maintain and the existing level of air pollution in the area. Then the pollution which will be produced by a proposed incinerator or other disposal facility can be estimated and the cost of reducing pollutants to an acceptable level determined.

The contribution of back yard burning and on-site incineration to air pollution should also be measured and evaluated, especially in communities with a significant level of air pollution. Such communities may find it advisable to ban all types of on-site burning and provide comprehensive municipal disposal services.

Sewage Disposal Capacity Survey

Before grinding garbage or other refuse into the sewers is considered as a possible disposal method, the municipality's existing sewage disposal capacity should be determined. Then the needed capacity should be determined and projected for the next 20 years, based on anticipated changes in population and sewage and refuse production. The amount of excess disposal capacity, if any, will affect the capital expenditures necessary for setting up a waste grinding system of disposal.

Comparative Costs Survey

The final basic factor in deciding on a disposal method is cost. The city naturally wishes to use that disposal method or combination of methods which will satisfactorily dispose of all refuse for the lowest unit cost. A careful analysis must be made to determine the cost of each possible disposal method.

As usual, two types of costs must be considered, capital costs and operating costs. Evaluation of capital costs can be done by obtaining estimates for construction, and appraisals of potential sites. Operating costs, however, are not so easily evaluated. Estimates can be based on the expenses at existing facilities, but it is necessary to compensate for variations caused by differences in the level of maintenance, size of the facility, per cent of capacity being utilized, and other factors. The market for steam, compost, metal, and other byproducts must also be determined since their sale can partially offset operating costs.

Both capital and operating costs are affected by the location and characteristics of the site chosen for the disposal facility. The information obtained in a comparative costs survey must be used in an economic analysis of two or three possible disposal methods each located on one or more potential sites before the least expensive method can be determined.

Considerations in Locating Disposal Facilities

The major considerations in locating solid waste disposal facilities are protection of surrounding land uses and minimization of collection and disposal costs. When locating a sanitary landfill, site geography and the future use of the site should also be considered.

Protection of Surrounding Land Uses

Advance planning must seek to minimize land use conflicts in the selection of disposal sites since the fear of land value depression often provokes widespread public opposition to proposed sites. The unfavorable public image of the odorous, unattractive, nuisance generating open dump is projected to any proposed new site. Opposition is often so strong that many otherwise wholly acceptable sites must be ruled out.

In order to help avoid land use conflicts, many state and local governments have passed laws and ordinances restricting the location of refuse disposal facilities. Illinois law requires that disposal sites be located either within the municipality where the refuse originates, or more than one mile outside the limits of any other municipality.[32] City zoning ordinances often restrict disposal operations to industrial zones, or permit disposal in several zones, but only as a special use. Some cities permit only the sanitary landfill method of disposal.[33] In the State of Michigan a sanitary landfill may be located in any zone since the State Supreme Court has ruled that a landfill is not a permanent use of the land.[34]

The principal nuisances associated with refuse disposal are dust, smoke, odors, fly ash, unsightliness, blowing paper, water pollution, rats, flies and other insects, and increased truck traffic. All of these problems can be minimized or avoided by competent planning and engineering when selecting the site and method of operation. Nevertheless, the fear that a refuse disposal facility will depress the value of near-by properties is difficult to overcome since it can neither be refuted nor confirmed by facts. According to the National Association of Residential Appraisers there is not enough information available to determine the effects of a disposal facility on near-by property values. The consensus is that in residential areas the value of contiguous properties would be depressed. Prevailing winds and landscaping would determine the distance for which values were affected. The maximum extent of influence should be one-half mile, and in most instances one-quarter mile.[35]

When new disposal facilities are being established it may be wise to use a remote site initially. After residents have become accustomed to the facility and realize that the nuisances often associated with disposal have been eliminated, sites closer to populated areas can usually be used without complaint.

If other factors are equal, an industrial or relatively isolated area is the best location for a disposal site. However, if other factors are not equal, or if suitable sites are not available in industrial or isolated areas, a properly screened site in another area should be acceptable. Where screening from highways and residential areas is not naturally afforded by trees or topography, a permanent perimeter fence and plantings are desirable, especially if the site will be used for more than five years. In addition, access to the site should be arranged so that truck traffic is not routed through residential areas.

Difficulty is often experienced in controlling dust and blowing papers at landfill sites. During dry weather the section of the landfill being worked should be kept damp, along with any unpaved portion of the access road. A light, movable fence, such as a snow fence or chicken wire fence should be set up around the landfill to confine blowing papers and other refuse. The fence should be cleaned regularly to prevent unsightliness.

Limbs, brush, and tree stumps are occasionally burned at landfills since they can cause difficulties in compaction. Smoke generated from this procedure can be a nuisance, even when burning is only allowed under rigidly controlled conditions. Burning should not be allowed, therefore, since public acceptance of the operation and proper location of future disposal sites are adversely affected.

If landfill operations are correctly carried out, a site near a residential area may be justified, not just because it is more centrally located than another site, but because the fill will actually improve the site itself.

Control of blowing papers can also be a problem at refuse transfer stations, in which case measures similar to those described for sanitary landfills should be instituted. In densely populated areas it may be desirable to utilize completely enclosed transfer stations. The capital costs for such facilities will be much higher than for open construction, but very careful control of any odors and refuse scattering is possible. The higher capital costs may be offset by the lower haul costs afforded by a more central location. One such station has been built in Washington, D. C., just a few blocks from the Capitol.[36]

Incinerator plants are generally located in manufacturing districts. But, a modern plant with effective air pollution control devices can be designed as an attractively landscaped, handsome structure which causes no complaints in a business or institutional district. Locating the incinerator in such districts usually precludes on-site ash disposal.

Care should be taken to avoid a location where the prevailing wind causes a down draft which could carry the stack effluent to ground level before it is properly dispersed. A nearby hill, ravine, or bank of high trees can cause stack discharge depression. Even if the incinerator is operating efficiently the fumes issuing from the chimney will be noticeable and undesirable under down draft conditions.[37]

Central grinding stations, if properly designed and operated, are nuisance free and can be located on any site where truck traffic will not cause problems. Doors are opened only to admit the refuse trucks, and the trucks are washed before they leave the station. Stored refuse can be sprayed with deodorizing chemicals and air vented from the building can be treated with ozone or masking agents.

Economic Considerations

The three economic factors which must be considered in locating refuse disposal facilities are collection costs, initial site costs, and achieving maximum possible savings through co-ordination of disposal facilities with other utilities.

Collection Costs. It is preferable to locate refuse disposal facilities as near as possible to the center of refuse production for the collection area served by the facility. The cost of collecting refuse is much higher than the cost of disposal. Therefore, every consideration should be given to locating disposal sites so that this cost is minimized. Time of haul is just as important as actual distances. The site should not be so located that collection trucks must use congested principal streets or highways to reach it.

The cost of transporting refuse to the disposal site determines the size of the area that can be served economically by one disposal facility. The necessary disposal capacity is then determined by the amount of refuse produced in the area to be served. All of these factors must be evaluated in order to determine how many disposal sites a community should have.

If the average haul to a disposal site exceeds ten miles it may be possible to save money by using transfer stations.[38] Since the sole purpose of a refuse transfer system is to minimize collection vehicle haul, one must determine the number of stations and the station locations which will minimize the total costs of hauling refuse from the collection routes to the transfer station, and operating, maintaining, and amortizing the transfer stations. A procedure for making this determination is presented in Appendix A.

It should be possible to generalize this procedure to determine the ideal location, capacity, and service area size for any type disposal facility.

Initial Site Costs. The purchase price of the land to be used for a disposal site, plus the cost of extending utilities to the site, constructing access roads, and doing preliminary grading are all examples of initial site costs which can make one site more or less desirable than another. Even if it is not used in the disposal process, an adequate supply of water under pressure should be available at disposal sites for fire control. Roads which will allow refuse transportation to fit properly into the community's traffic pattern should be located within reasonable distance of the site so that the cost of constructing the necessary all-weather access facilities can be kept within justifiable bounds. Finally, the site should have sufficient level land so that excessive grading will not be necessary before the disposal facility can be constructed.

Sanitary landfill sites should have sufficient disposal capacity to justify the total cost of initial site improvements. These improvements include not only those discussed in the preceding paragraph, but also the screens, fences, scales, restrooms, and other improvements necessary before disposal operations can be carried out. The total cost of all necessary improvements must be divided by the cubic yards or acre feet of usable disposal volume that can be developed at the site. The resulting cost per unit of volume can then be used to compare different sites and determine which is more economical.

Co-ordination With Other Utilities. Generally the possibilities for achieving savings through co-ordination of waste disposal operations with other utilities have been overlooked.

Waste heat from incinerators could be better utilized. Many possibilities exist for combination of refuse incineration with water supply, power production, and sewage treatment. Already an incinerator at Hempstead, New York, uses waste heat for desalination.[39] Steam can be produced from incineration at the rate of one to three pounds of steam per pound of refuse burned.[40] The steam can then be used for district heating, generating electricity, and other purposes. Atlanta receives $140,000 a year from sale of steam to heat downtown buildings.[41] It is estimated that New York could use refuse to generate as much as one-quarter of its electrical power.[42] Waste heat can also be used for drying sewage sludge which can then be burned or sold as a fertilizer or fertilizer filler. In addition, sewage treatment plant effluent can be used in the incinerator's wet scrubbers, thereby conserving the water supply.

Composting can also be co-ordinated with sewage treatment. The increasing paper content of refuse causes some problems in maintaining the carbon-nitrogen ratio desirable for composting. This ratio can be reduced by adding sewage sludge or slaughterhouse wastes.

Additional Considerations in Locating Sanitary Landfills

Because of the extreme variability in local conditions within any area, sites being considered for sanitary landfill should be individually evaluated with respect to geological conditions and possible undesirable effects from filling. Possible uses of the site after filling is completed should likewise be considered.

Geological Considerations. Shallow acquifers are usually hydrologically connected with the surface and are subject to contamination by sanitary landfill operations under certain conditions. The three mechanisms by which ground water pollution occurs are, "...vertical leaching by percolating water, and the transfer of gases produced during decomposition by diffusion and convection."[43] In any case serious nuisances and health hazards result. These same mechanisms can also leach soluble salts and alkalies from incinerator ash fills.

Any time a landfill becomes saturated with water the threat of pollution is serious. Intermittent saturation can occur as a result of flooding with surface water runoff, infiltration by rainfall, or addition of water to promote compaction. Therefore, both during the landfill operation and after its completion, provisions must be made for minimizing runoff onto the fill, preventing erosion of the fill, and draining off precipitation. Standing water must not be allowed to collect at any point on the site. In addition the site must be protected from flooding on nearby waterways.

Constant or intermittent saturation of a landfill by a high ground water table is particularly hazardous. Operating a sanitary landfill in the edge of a body of water can also cause pollution. Contamination from garbage seeping into San Francisco Bay has been serious.[44] A sanitary landfill should never be carried below the level of the water table.

Landfill sites should be kept away from drinking and irrigation water supplies. Even if the direction of ground water flow is away from all areas of present or projected ground water use, future pumping of water from the shallow acquifer could cause diversion of the flow from the disposal site toward the area of discharge. The risk of introducing contaminants into shallow aquifers is greatest where permeable earth materials are present between the source of contamination and the aquifer.

The type of earth materials available for cover is also important. When cover material is spread over the refuse and compacted it performs several vital functions. The cover prevents flies from laying eggs on the refuse and rodents from invading the fill. Fly eggs and larvae which complete their development in the fill are prevented from emerging as adult flies. In addition, the cover seals in odors, reduces the fire hazard, keeps rain water out, and helps produce a dense, stable fill.

The available cover material should be a type which can be compacted to provide a tight seal, does not crack excessively when dry, and is relatively free of putrescible materials and large objects.[45] Sandy loam is the best cover material as it provides a tight, easily maintained cover. Other materials can be used, but they frequently require additional work for excavation, compaction, or cover maintenance. Coarse soils may be difficult to handle and deeper cover may be required to prevent rodent infestation. Clay soils can present operational problems in wet weather, may crack when dry, and may be difficult to excavate during winter. United States Soil Conservation Service soil surveys are helpful in locating landfill sites with suitable soil conditions. If sufficient acceptable cover material is not available on the site, the decision to import cover must be based on a careful economic analysis. Importing cover material is an expensive operation.

The type of cover material available also determines the kind of equipment necessary for excavation and can significantly affect landfill operating costs.

> Loose sand and loam mixtures, loose sand and clay mixtures, soft decomposed granite, well-fractured or loosely cemented sedimentary deposits, etc. can be excavated easily with a bull-dozer or carryall scraper. Clay, adobe, well compacted sand and clay mixtures, well cemented sedimentary deposits, partially decomposed granite, and the like often require loosening with a ripper prior to bulldozer or carryall excavation. (Sites) with geological structures consisting of well-consolidated sedimentary deposits, poorly fractured and poorly weathered igneous or metamorphic formations of any solid rock should be avoided. . . .[46]

Finally, a principal criterion in selecting a canyon site is the canyon's physical configuration. In order to minimize energy requirements for vehicles moving from the mouth of the canyon to the head, a relatively level botton grade is desirable. The canyon should be long, narrow, and flat bottomed since almost all cover material is excavated and hauled from the canyon sides.[47]

Effects of Filling. The effect a landfill will have on natural drainage in the area must be carefully considered. A landfill should never alter the drainage pattern in a manner that adversely affects adjacent property. Landfill operations in low areas must be planned so that the fill does not become a dam which prevents runoff from escaping. Naturally, canyons must be filled from the head down.

When using sanitary landfills to raise the elevation of flood plain areas, great care must be exercised to see that the fill is properly designed and located so that flood stages will not be adversely affected. A number of landfills have encroached upon the cross sectional area of a waterway and reduced the hydraulic efficiency of the channel. The result is higher upstream flood stages and greater flood damage.

On a larger scale, a landfill can alter the ecology of a whole area. Filling along the edges of San Francisco Bay, for example, has reduced the amount of oxygen available in the water for marine life and for pollution abatement.[48] Ecologists are seriously concerned about the effects of filling coastal marshes. Some feel that the ecology of the whole continental shelf is being altered on the Atlantic coast. As wetlands have disappeared under landfills, some species of marine life have begun to vanish. Along the mid-Atlantic coast, weakfish, croaker, and menhaden are declining, and oyster harvests have dwindled.[49]

Future Use of the Site. Other factors being equal, a site which can be made usable by filling is more desirable than one which will not be improved. The best landfill sites are those which are lower than adjacent lands, and which can be raised in grade without damaging side effects. Such sites include marshes, canyons, tidal lands, and abandoned mines, quarries, and sand pits. Nevertheless, land reclamation is a secondary benefit. The main purpose of a landfill is effective refuse disposal.

Completed landfills have been used successfully for parks, playgrounds, athletic fields, golf courses, parking areas, aircraft landing fields, equipment storage areas, and light industrial or commercial construction. Co-ordination of landfill operations with park and recreation planning may enable a municipality to obtain new park sites much sooner than might otherwise be possible. If the landfill is properly constructed, it can be utilized as little as two years after completion of the fill. Subsequent settling is usually minor and can be corrected at little expense. Ultimate settlement commonly ranges between five and ten per cent.[50]

The final use of the landfill site may be restricted by its surroundings and the amount of settlement. The problem of settling increases with the weight of any building. Although one-story buildings have been constructed on filled sites without bad results, open land uses, where settling causes no great difficulties, are more satisfactory. For heavy construction it is best to sink piles through the fill to a more stable ground level. In one case where a multi-story school building was constructed on a landfill the walls were so badly cracked after five years that the community was faced with great expense to correct the difficulty.

Methane gas produced in the decomposition process of the fill can also cause problems. Any building which might allow seepage into areas with restricted air movement, such as a basement, must have adequate ventilation facilities. In addition, water pipes and sewers passing through the fill will require special protection against corrosion, contamination, and settlement.

The future usefulness of a landfill may be seriously limited if it is improperly constructed. A San Francisco landfill with poorly compacted lifts up to 12 feet deep covered with rocky soil has settled badly and spontaneous methane gas fires are a problem.[51] These difficulties have not occurred in well compacted landfills with lifts less than six feet deep.

Planning Studies

Land needed for solid waste disposal facilities is also in demand for many other uses. Suitable sites should be identified and reserved for that use as part of a municipality's general development plan. The following studies can help determine appropriate locations for such facilities.

Solid Waste Disposal Facilities Study

The object of a solid waste disposal facilities study is to estimate the present and future net demand for disposal facilities in the planning area, and to determine, in general, the areas where such facilities will be needed.

Estimating Refuse Volumes. Effective refuse disposal planning cannot be carried out without reliable data on the quantities of refuse being produced. For this reason each truck load of refuse should be weighed and its collection route noted as it is delivered to the disposal site. Weighing is the only method for measuring refuse which yeilds data valid for comparative purposes.[52] Weighing also provides the basis for supervision of collection crews and cost analyses of disposal operations.

For a study of refuse volumes the city should be divided into areas delineated on the basis of existing collection routes. The area approach is recommended because of the desirability of locating disposal facilities near centers of refuse production in order to minimize haul costs. For each study area it is desirable to know the total annual refuse production, monthly and daily variations in refuse volumes, and periodic variations in the proportion of ashes, garbage, and combustible and noncombustible rubbish.[53] All solid wastes must be considered, including demolition, industrial, and agricultural wastes.

Future refuse production volumes should be projected for each study area. These volumes are functions of the population to be served, the land use in the area, and the increasing per capita volume of refuse production. The projections should be based on refuse production data collected in the planning area during the preceding ten years. If these data are not available, the projections can be based on current refuse volumes and the anticipated national increase in average per capita refuse production.

Refuse production volumes for each collection area should be correlated with information on the area's population, land use, and economic and social levels. Per capita refuse production volumes can be calculated for residential areas of different economic and social levels. For nonresidential areas the refuse production can be calculated on the basis of tons of refuse per 1,000 square feet of floor space for each major land use type.

Once the above production figures have been obtained, future refuse volumes can be projected for each collection area, and for areas where new growth is anticipated. Naturally these projections must take into account the anticipated changes in the character of each area. Increasing per capita waste production, the impact of garbage grinders and apartment house incinerators, and future changes in regulations regarding on-site disposal must also be considered.

Determining Disposal Facility Demand. After a projection of future refuse volumes has been made it is possible to evaluate the community's existing inventory of disposal facilities with respect to present and future needs. All existing refuse disposal facilities which are appropriate for use should be included in an inventory and analyzed in terms of capacities available for use within the study period.

By comparing the available disposal capacities, as determined in the disposal facility inventory, with the present and projected refuse volumes for each collection area, the net demand for new disposal facilities during the study period can be determined. In addition, areas which might be more economically served by their own centrally located disposal facility can be identified.

Upon conducting an inventory many communities find that their disposal facilities are badly overloaded or soon will be. Communities using the landfill method of disposal may find that they are running out of land suitable for filling. The change from landfill to some other method must be made while landfill sites remain available for disposal of those solid wastes which cannot be incinerated, composted, salvaged, or disposed of in some other manner.

Site Survey

After areas have been identified which will need additional disposal facilities during the planning period, a site survey should be conducted to identify sites within these areas which are available for refuse disposal facilities. As part of the survey each potential site should be evaluated in terms of possible land use conflicts and other criteria discussed under "Considerations in Locating Disposal Facilities."

After the survey is completed the city should acquire the best sites in accordance with a refuse disposal plan for meeting anticipated disposal needs in critical areas. The new sites should be generous in size. A larger site will permit future needs to be met without the struggle often associated with new site selection. Cities using methods other than sanitary landfill should acquire sufficient landfill capacity to dispose of all materials which cannot otherwise be disposed of during the life of the primary disposal facility, usually 20 to 30 years. Cities presently using landfill which cannot acquire enough space to meet their needs for at least 20 years should begin planning for a change to some other disposal method.

Land Use Study

Around potential disposal sites, the land uses in areas which would be affected by the disposal facility should be surveyed and analyzed in detail. The exact use of every parcel of land within one-half mile of the proposed disposal facility should be determined and mapped. In addition the conditions of structures in the area should be evaluated and blighted areas defined. This analysis will help determine the effect that any adverse features of the disposal operation might have on surrounding land uses.

The entire area from which the disposal facility operations can be seen, heard, or smelled will be affected, as well as areas bordering roads which will carry heavy truck traffic. The extent to which existing or proposed buffers will screen the disposal facility from sight and dampen noises should be carefully evaluated. The area which would be affected by odors or other types of air pollution must also be determined. This can be done through wind tunnel experiments with models of the site,[54] or by using balloons to trace air currents.[55] If there is any question of unusual meteorology associated with the site the plume behavior should be predicted and analyzed by a specialist. If there are hills nearby, a meteorological study should be conducted to determine adequate stack height and the frequency and effects of temperature inversions.

The land use study will also provide a guide in determing the most appropriate use of a completed landfill. The future use of a landfill site should be determined before filling begins. "When the final use of the site is known before hand, the landfill can be planned so that suitable building sites, roads, and utilities can be provided. Final grades can be established and allowances made for landscaping and adequate drainage."[56] Where buildings, streets, or runways are to be constructed on the fill, it is possible to reduce settling by improving compaction.

Geologic Survey

A geological survey is one of the most important studies required in selecting a sanitary landfill site. Such a survey will permit evaluation of the ease of excavation, the risk of water pollution, and the probability of lateral gas movement. Whether enough suitable cover material is available at the site can also be determined. The volume of available cover material should equal at least 25 per cent of the total volume available for filling.[57]

For sites which will be used for disposal methods other than sanitary landfill, the geological survey is a sound advance means of estimating foundation costs and difficulties.

If reliable survey data are not already available, tests should be carried out on the site to determine its geological characteristics. The tests should include enough borings to give a valid indication of the sequence, nature, and thickness of the subsurface materials. Borings should be taken at a minimum rate of one per acre. The percolation rate should also be determined as inclement weather can cause operational difficulties at sites with low rates.

Transportation Study

Existing streets in the vicinity of potential disposal sites should be inventoried in terms of width, condition, bearing strength, and volume of traffic carried. Generally, traffic congestion and dust and noise nuisance to residences can be minimized by routing traffic generated by the disposal facility over secondary roads and collector streets. All streets used must be adequate for the gross weight of collection or transfer vehicles. Refuse collection and disposal services should be closely co-ordinated with plans for new street construction.

Economic Analysis

The objective of an economic analysis is to determine which of the acceptable disposal sites is most desirable from an economic viewpoint. The most accurate results can be obtained by using discounted cash flows to determine the present value of all income and capital and operating expenditures anticipated during the life of the disposal facility.[58] The site having the lowest net present value will be the most economical.

The first step in computing the net present value is to determine what rate of interest to use for discounting the cash flows. The average rate of interest the municipality is paying on borrowed funds is normally used. The second step is to predict the cash proceeds which will be produced by the disposal facility during each year of its life. These proceeds must then be discounted to determine their present value. The third step is to predict the capital and operating expenditures required during each year of the disposal facility's life and discount them to their present value. The present value of the expenditures minus the present value of the proceeds is the net present value.

As stated previously, for landfill sites the results of this analysis should be given as a cost per unit volume. For other types of disposal facilities the cost is determined on a per unit of 24 hour capacity basis.

Care must be taken to include all relevant costs and income. Otherwise the results of the analysis will be invalid. Capital costs will include the cost of the disposal site, the cost of constructing the disposal facility and access roads, and the cost of scales, tractors, and other equipment. For the purposes of this analysis operating costs will be the cost of the actual disposal operation, plus the cost of transporting the refuse from collection route termini to the disposal site. Transportation costs must be included because some disposal methods, such as incineration and composting, have greater flexibility of location than others, such as sanitary landfill.

The effect of the disposal facility on surrounding property values must not be overlooked. Any decrease in such property values is a cost of the disposal facility and should be included in the economic analysis along with any ultimate benefits.

CHAPTER IV

RECOMMENDATIONS

For today's sprawling metropolitan areas, it is inevitable that refuse disposal take place near, if not in the midst of, urban development. Yet, all too often sanitary landfills are neglected or improperly operated and soon degenerate into open dumps. Incinerators are overloaded, resulting in air pollution; or unreceivable refuse and incinerator residue are allowed to accumulate on an unscreened site, creating unsightly conditions. In order to win public acceptance of the disposal facilities needed in metropolitan areas the difference between what is known about proper refuse disposal and what is generally practiced must be reduced. Methods now available can be used to dispose of refuse efficiently and inconspicuously in built-up areas without detrimental effects on surrounding properties. If design and operating standards are not adhered to, however, any method will be a prolific nuisance source and unacceptable in an urban environment.

Many municipalities in metropolitan areas do not have suitable sites available for landfill, and some do not have sites available which are really suitable for any disposal method. This problem is best solved by shipping the refuse across county and municipal boundaries to other parts of the metropolitan area for disposal. This is not always possible, however. Neighboring political jurisdictions are often unwilling to allow disposal of someone else's wastes within their boundaries. Natural limitations and restrictive political boundaries can make it virtually impossible for cities to provide economical waste disposal service on an individual basis. Without access to natural formations suitable for landfill, cities must resort to more expensive methods.

Even when suitable disposal sites are available, some political jurisdictions having the responsibility for waste disposal are too small to have sufficient resources for the job. While refuse collection can be adequately handled by individual cities, disposal of the collected refuse must be considered as a regional problem if the public is to receive satisfactory and economical service. The problem has been at least partially solved in some areas by private companies which dispose of the wastes collected in several different communities. As with all instances of private disposal, the communities' responsibility is limited to insuring that no nuisances are created.

The volume of solid wastes being forecast for metropolitan areas in the future is too formidable to consider in the absence of effective, metropolitan disposal planning programs. The first objective of such planning should be to end the fragmentation of solid waste disposal operations among small political subdivisions. State legal authority should be obtained for establishing and financing refuse disposal services on an area-wide basis. Then disposal sites can be located to serve disposal districts embodying communities with common waste problems. Some cities currently share disposal facilities on a fee or pro-rated cost basis. But the best general solution is probably the system used in Los Angeles where all refuse disposal is handled by the county.

APPENDIX

APPENDIX A

TRANSFER STATION LOCATION[59]

The basic function of a refuse transfer and haul operation is to minimize the total cost of transporting refuse from the collection route termini to the disposal facility. The closer transfer stations are located to each other the smaller will be the individual station capacity and the higher will be the transfer station cost for handling each ton of refuse. The problem is to determine the optimum number of transfer stations or, conversely, the optimum distance between transfer stations. Once determined, this fixes the collection zone radii. For any particular situation, an approximation to this determination must be developed before a final choice is made between transfer and haul or direct haul, since unit costs will vary with collection zone sizes and station capacities. If transfer and haul appears to be economical, one may proceed with the determination of R, the optimum radius of the collection zone.

In order to accurately define R, it is necessary to determine the following quantities:

A The charge for each working day for amortization of all capital costs of the transfer station.

C_c The average hourly cost for operating a collection unit (one collection vehicle plus one collection crew) for the drive from the collection route termini to the transfer station and return.

C_h The cost per ton for the haul from collection route termini to the transfer station plus the cost of the return of the unloaded collection vehicle to the collection route.

C_t The per ton cost of the transfer operation.

D The average collection zone population density in persons per square mile.

N The number of collection days per week.

O The average cost per working day for operating the transfer station, including the costs for labor, maintenance, and utilities.

V The average collection vehicle haul speed.

w The pounds of refuse produced per capita per day.

W The average collection vehicle payload.

The transfer station will be at its optimum location if the sum of C_t and C_h is minimized. To determine C_t we first determine the transfer station capacity Q:

$$Q = \frac{w \pi R^2 D}{2000} \times \frac{7}{N} \tag{1}$$

Then:

$$C_t = \frac{A + O}{Q} \tag{2}$$

C_h can be determined by the following formula:

$$C_h = \frac{2 \times 0.6R}{V} \times \frac{C_c}{W} \tag{3}$$

This is based on the assumption that the average distance from the transfer station to the collection route termini in the collection zone is about 0.6 R miles, as has been determined for Los Angeles. A factor of two is applied since a round trip must be made.

We now have:

$$C_t + C_h = \frac{A + O}{Q} + \frac{2 \times 0.6R}{V} \times \frac{C_c}{W} \tag{4}$$

If functions are defined for A and O in terms of Q, it is possible to find R by taking the derivative of $C_t + C_h$ with respect to R and setting the derivative equal to zero.

If the functions for A and O in terms of Q are not defined, it is still possible to find R. First construct a curve by plotting A + O against Q. Then, by taking values off this curve and substituting them into equation (4) it is possible to plot $C_t + C_h$ against R and determine what value of R will give the smallest value of $C_t + C_h$.

> It is obvious that the transfer and haul process becomes economical only if distances to disposal facilities are greater than some critical distance. This distance is a function of unit transfer cost as well as unit haul costs for both collection and transfer vehicles. For any given area these relative costs must be calculated and a decision based upon them. This analysis can only be made after consideration of proposed transfer system layouts including station capacities and methods of operation, vehicle design and costs, and other relevant factors.
>
> The cost of direct haul can be estimated by determining the total required time for a round trip to the disposal site, and multiplying by the applicable collection crew and vehicle hourly charge. The total costs for transfer and haul will be the cost of the round trip in the collection vehicle from the

subject area to the transfer station (C_h); plus the cost of the transfer operation (C_t); plus the cost of haul to the disposal facility in transfer vehicles. A comparison between the resultant direct haul versus transfer and haul figures on a per ton basis leads directly to a rational decision.

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